How did the east-pacific temperature anomaly affect water quality trends in the urban fjord, Puget Sound

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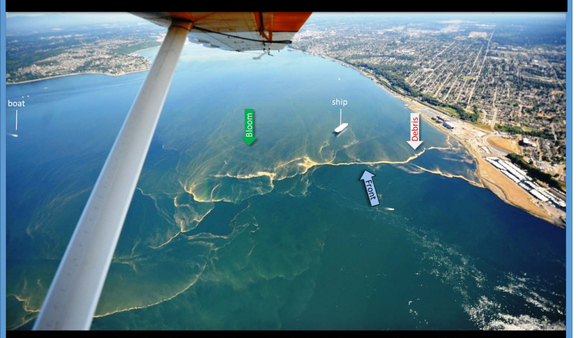
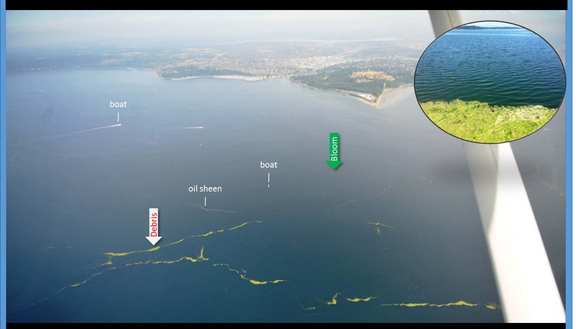
Large Noctiluca bloom in Central Basin of Puget Sound 6-8-2015



Large Noctiluca bloom surfacing and gathering in large quantities at tidal front.
Location: Commencement Bay (Central Sound), 3:32 PM.

Large Macro-algae mats in Central Basin of Puget Sound 7-6-2015

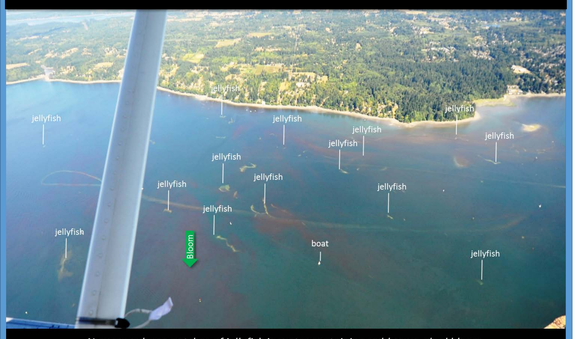


Extensive accumulations of organic debris, a brown algal bloom, and a large oil sheen.
Location: Between Port Madison and Shilshole (Central Sound), 3:05 PM.

Large jellyfish aggregations respond to warm BLOB water 10-29-2014

Extensive smacks of moon jellies both in size and density with pinkish tint.
Location: A. On the water, B. From air showing location on the water, Budd Inlet (South Sound), 3:50 PM.

Large jellyfish aggregations occur throughout the year of 2015, 8-4-2015



Numerous large patches of jellyfish in water containing red-brown algal bloom.
Location: Budd Inlet (South Sound), 3:12 PM.

Abstract:

Long-term monitoring data collected by the Washington Department of Ecology show that nutrient concentrations have significantly increased and that nutrient ratios and phytoplankton biomass have steadily changed in Puget Sound. Some biochemical markers that could be interpreted as a result of human impacts, have approached critical turning points with implications for the cycling of energy and material. At the end of 2014, a large temperature anomaly originating in the Pacific Ocean brought very warm water into Puget Sound, which extended throughout the water column and surpasses marine water temperature records. Coinciding with the warm water condition, 2015 is also remarkable for expected drought conditions in summer. Typically, Puget Sound has been considered a diatom-dominated cold-water ecosystem system. Since phytoplankton species will likely respond to warmer water, differences in the physical structure of the water column, and a different nutrient balance, recent conditions are potential future scenarios for changing climatic conditions. High ammonium concentration and high jellyfish abundances coincided with the appearance of warmer water during the mild winter of 2014-2015 setting the stage for the unprecedented conditions in 2015. Evolving conditions will be presented and discussed in context of existing long-term trends in water quality, nutrient balances and phytoplankton biomass.

Discussion:

In recent years symptoms of eutrophied coastal environments (Vasas et al. 2007) have been highly visible in Puget Sound on a basin-wide scale (Eyes Over Puget Sound (2011-2015). Typically Noctiluca, a opportunistic dinoflagellate, blooms in June, followed by large drifts of macro-algae in July to August and large aggregations of jellyfish in September to October. **In late 2014 and 2015 the seasonality of visible symptoms was different when Blob entered Puget Sound.**

- **Jellyfish mass aggregations peaked in fall 2014 when water temperatures increased Puget Sound wide in response to water of the Blob.**
- **Jellyfish patches persisted through 2015 and showed up in high numbers in multiple places.**
- **Macro-algae mats began as early as May and peaked in July/August of 2015.**
- **Noctiluca blooms in Central Sound were large in size and occurred in high numbers in Central Sound and East Sound San Juan Islands.**

The timing when these putative biological eutrophication indicators (pictures on the left) rapidly increased coincided with the onset of the drought. The Blob and the drought created anomalies in salinity and water residence time in Puget Sound. By June initially low salinity due to premature snowmelt switched to high anomalies with a slowing of estuarine circulation. **This created a setting for conventional pollutants to have a larger effect on Puget Sound biota.**

Coastal Upwelling

(NOAA)
Upwelling was atypically strong in May and June 2015 and generally stronger than the previous years. A. Upwelling index, B. Anomalies of the Upwelling index.

A.

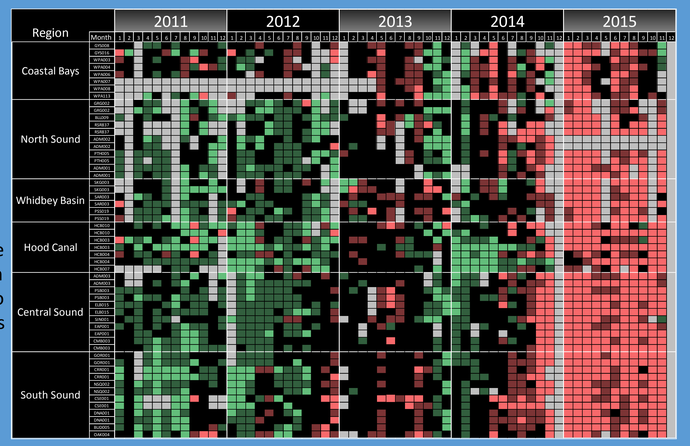
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2011	-22	-11	-123	1	5	17	16	18	-5	-9	-48	-4
2012	-77	-50	-57	-15	11	2	39	11	18	-14	-88	-53
2013	-6	-14	-6	17	2	5	84	2	-3	2	-10	-2
2014	-17	-72	-34	-14	2	24	34	35	-1	-62	-49	-88
2015	-49	-27	-18	-1	45	56	35	17	1	-18	-9	-143

B.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2011	68	36	-103	1	-12	-8	-18	-5	-9	30	39	96
2012	13	-3	-36	-15	-6	-23	6	-11	14	25	-1	47
2013	84	33	15	17	-16	-21	50	-20	-7	40	78	98
2014	73	-24	-13	-14	-15	-2	1	13	-4	-23	38	12
2015	41	21	3	-1	28	30	2	-6	-2	20	78	-43

Temperature anomalies

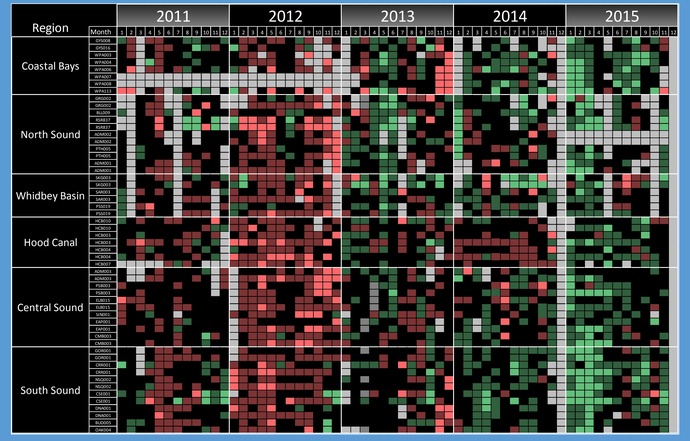
Ecology's long-term marine monitoring program visualizes anomalies using heat-maps for its monthly routinely sampled station network. Colors indicate conditions that fall outside of 50% of the historical monthly samples data. Data that exceed the historical data records from 1999 to present are highlighted in brighter colors with red being above and green below expected values (grey are missed sampling events). While 2011-2012 were years were Puget Sound was colder than expected water, the Blob started to rapidly penetrate into Puget Sound by October 2015 raising water temperatures quickly to unprecedented levels on a massive scale. At the end of September coastal 2015 downwelling, higher Fraser River discharge and weak tidal mixing across Admiralty Reach created conditions that allowed Blob water to enter Puget Sound on a massive scale.



Oxygen anomalies

Oxygen concentrations in Puget Sound were higher in 2012. By 2013-14 favorable oxygen conditions disappeared with the exception of Hood Canal (2014). With the onset of Blob water entering Puget Sound, oxygen concentrations quickly fell to unprecedented low values for winter and spring in Puget Sound. Despite warm water and optimal algal growth conditions (sunny, warm) oxygen concentrations rebounded.
We attribute the improving oxygen conditions to a combination of likely factors:

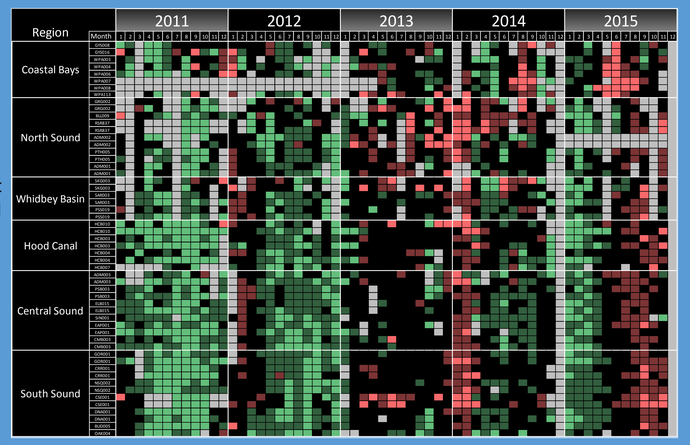
a) The drought, weakening salinity stratification and allowing for increased vertical mixing and oxygenation of the water column,
b) Potential for higher primary productivity due to prolonged sunny conditions.



Salinity anomalies

Salinity was much lower in 2011-2012 and lower in 2014 with winters in 2012, 2014 showing seasonal unusually higher salinities. 2015 was very different. Salinities were very low in response to very high river flows and a premature melting of the snow pack. By June salinities increased to higher anomalies in response to the drought and record breaking low river discharge into Puget Sound and the Salish Sea. The Fraser River being the largest contributor of freshwater to the Salish Sea rapidly dropped in June coinciding with the increase in salinity.

In coastal bays, in comparison, salinity increased sharply in May and June to record levers. The pattern is very consistent with unusually strong coastal upwelling along the coast for springtime.



Fraser River (Environment Canada)

The Fraser River is the largest freshwater contributor to the Salish Sea. Its flows are a reflection of the snowmelt in the rocky mountains. Its flow dictates the freshwater balance of the entire Salish Sea and drives estuarine circulation in the Strait of Juan de Fuca. Estuarine circulation connects coastal conditions with water in Puget Sound. Fraser River flows responded to the warmer air temperature coinciding with the Blob. By October 2014 flows were much above normal lasting into April which lowered Salish Sea surface salinities. By June flows dropped sharply to very low flows in response to the drought